COLORED STONES
ASSIGNMENT 8
DOUBLE REFRACTION AND PLEOCHROISM IN IDENTIFICATION
IDENTIFICATION, PRODUCTION, MARKETING, BUYING

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I. POLARIZATION.

It has been pointed out that light may be considered as having a wave motion. When ordinary light travels in air or space, the wave motion is not confined to a single plane. There are many waves vibrating in ALL directions about the path of the beam. When this vibratory motion is limited to a single direction, or plane, the light beam is said to be POLARIZED.

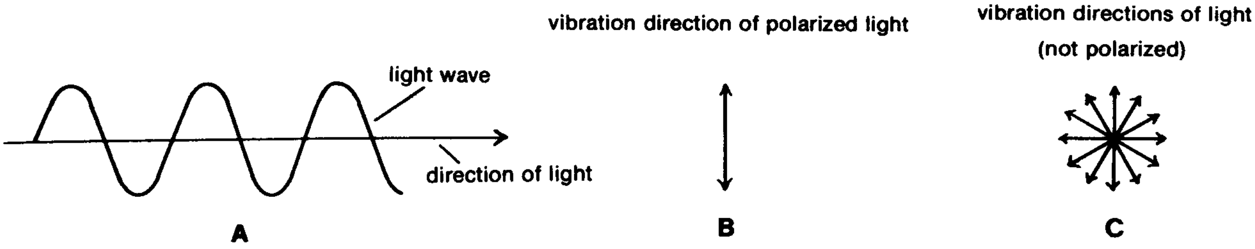

vibration direction of polarized light
vibration directions of light
(not polarized)
light wave
direction of light
A
B
C

Figure 1

Figure 1A shows the simple wave motion of light in a single plane; i.e., corresponding to the plane of this paper. A "head-on" view of this beam is shown in Figure 1B; the arrows merely indicate the vertical directions of vibration (the light would be traveling either straight at you or directly away). Since the beam is vibrating in only one plane, it is polarized. An ordinary beam of light actually consists of waves vibrating in all directions, as indicated in Figure 1C.

II. SINGLE AND DOUBLE REFRACTION.

Ordinarily, when light passes through a piece of glass, it is slowed down and, if it enters at an oblique angle, it will be bent. This light enters the glass vibrating in all directions and leaves the glass vibrating in all directions.

With some materials, this is not the case. For some gem species, due to their crystal structure, light entering them is split into two beams traveling at different speeds. Since each of the two beams is traveling at different speeds, each will have a separate refractive index. Most refractive index tables list the high and low indices for these materials. At the same time that the light is split into two

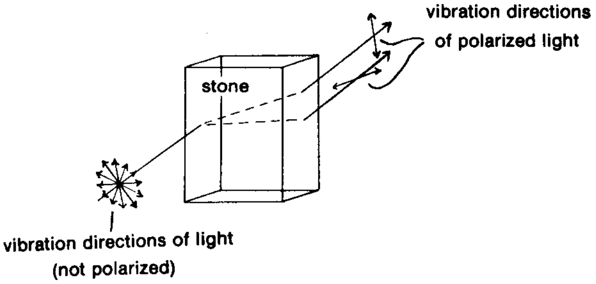


Figure 2

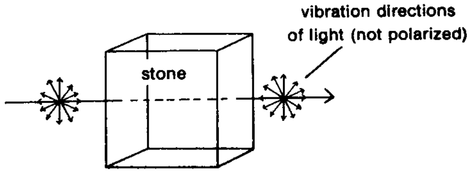
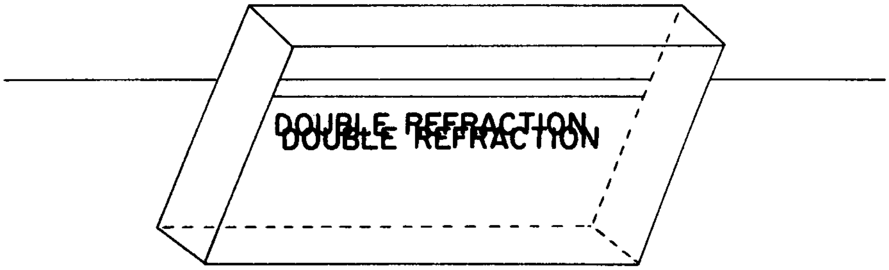


Figure 3

beams, it is also polarized so that each beam is vibrating at right angles to one another (Figure 2). Materials that have the ability to split light entering them into two beams vibrating at right angles to each other are called DOUBLY-REFRACTIVE. Materials that do not effect light in this way, such as glass, are called SINGLY-REFRACTIVE (Figure 3). Doubly-refractive stones crystallize in the hexagonal, tetragonal, monoclinic, triclinic, and orthorhombic systems. Amorphous material as well as minerals crystallizing in the cubic system are singly-refractive.



doubled image seen through calcite (birefringence - .172)

Figure 4

The example used to describe refraction was that of a stick in water. A stick placed in water will appear to be in another place then it actually is because light is bent, refracted, as it passes through the water. Light passing through a doubly-refractive stone is split into two beams that are bent to different degrees since they are traveling at different speeds. Because of this, objects seen through a doubly-refractive stone will appear in two different places. This is called DOUBLING (*Figure 4*). Inclusions, back-facets, and objects placed behind a *doubly*-refractive stone will appear as doubled images. If the two refractive indices for the stone are far apart, for example, 1.654 to 1.690 for peridot, the doubled images will appear far apart. If the two refractive indices are closer together, as with 1.762 to 1.770 for corundum, the doubled images will appear closer together. The amount of separation between the two refractive indices, and thus the amount of doubling possible, can be determined by subtracting the low refractive index given in the table from the high refractive index. The amount of separation of the two refractive indices obtained in this way is called BIREFRINGENCE. Birefringence shows the strength of double refraction.

Each doubly-refractive gem species has its own birefringence. For example, taking an R.I. reading on the refractometer gives an R.I. of 1.624 and another reading a 1.644. Subtracting the two gives a birefringence of .020. Checking your reference sources in this course material and the Handbook of Gem Identification shows that these figures fit tourmaline.

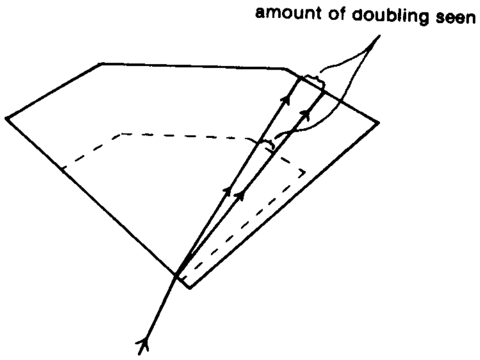
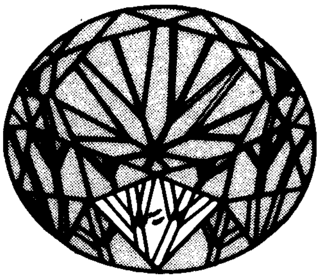


Figure 5

Birefringence can also be estimated by judging the amount of doubling. This requires practice and experience since the size of the stone has to be kept in consideration. The larger the stone, the more doubling it will show compared to a smaller stone of the same species (Figure 5). Also, stones must be examined in several directions because the amount of doubling varies with direction. To estimate birefringence, the maximum doubling must be used.

From this discussion, it can be seen that double refraction affects light passing through gemstones in several interesting ways. It becomes more important as you discover which stones are doubly-refractive and thus can show birefringence and doubling, and which stones are singly-refractive and cannot. For example, ruby and garnet can have refractive indices in the same range, but ruby is doubly-refractive and garnet is singly-refractive.

For another example, zircon is often used as a diamond substitute but zircon is doubly-refractive and diamond is singly-refractive. Looking through the crown facets of a zircon will usually show the back facets as widely separated doubled lines. The back facets of a diamond will appear as single lines.



double facet junctions

Figure 6

III. OPTIC AXES.

Not every direction in a doubly-refractive stone is a direction of double refraction. Instead, every such stone, depending on the crystal system to which it belongs, has either one or two directions of single refraction; i.e., directions in which light is not polarized. These directions are referred to as OPTIC AXES. If light enters a doubly-refractive material along a path parallel to its optic axes, it is not broken into two beams but is refracted as a single beam, just as though it had been refracted into a singly-refractive stone. Gems of the tetragonal and hexagonal systems have one such direction of single refraction, or optic axis (UNIAXIAL, "uni" meaning "one,") whereas those stones of the orthorhombic, monoclinic and triclinic systems have two optic axes (BIAXIAL, "bi" meaning "two.") (See Figure 7).

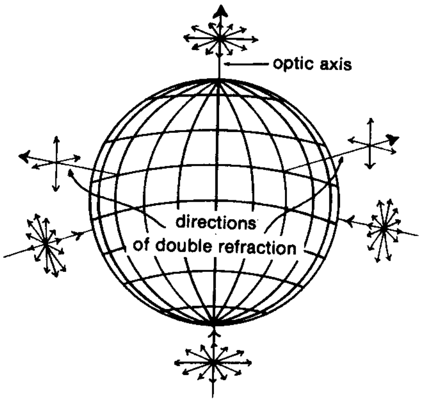


Figure 7

IV. PLEOCHROISM.

When a beam of light strikes a colored object, some of the wavelengths are absorbed while others are reflected back to the eye. This, briefly, is the cause of color. If the object absorbs all the wavelengths except red, only the red wavelengths will be returned to the eye and the object will appear red.

When a beam of white light enters a colored doubly-refractive gem material, the wavelengths of each of the beams vibrating at right angles to one another may be absorbed differently, causing each beam to emerge as a different color. This is called PLEOCHROISM (pronounced PLEE-oh-kro-izm; from the Greek "pleo," meaning "more" and "chorma" meaning "color"). With the exception of the one direction of single refraction, uniaxial stones may show TWO pleochroic colors and are said to exhibit DICHROISM (pronounced DYE-kro-izm; "di" meaning "two") or to be DICHROIC (pronounced dye-KRO-ik). Biaxial stones may show a total of THREE pleochroic colors, but only two will be visible in any one direction. These gems are said to be TRICHORIC (pronounced try-KRO-ik; "tri" meaning "three") and to exhibit TRICHORISM (pronounced TRY-kro-izm.) It is possible for a doubly-refractive stone not to show pleochroism but, if pleochroism is present, it proves double refraction. Singly-refractive stones cannot show pleochroism. Uniaxial stones will never show more than two colors but biaxial stones may show three colors. For this reason, three pleochroic colors proves that the stone is biaxial. Both uniaxial and biaxial stones may show only one or two colors, for in some gems there is no discernable difference in color in the different directions.

In addition to its value in gem testing, pleochroism increases the beauty of some gems. In directions OTHER than along an optic axis, two different colors emerge from pleochroic stones, but they blend so that the eye usually sees them as one color, just as the beams of two colored spotlights on a white surface produce a blended color. In ruby, for example, both orangy red and violetish red continually emerge, but the eye sees only the blended color, which is often more attractive than either color alone. On the other hand, the color emerging from a direction PARALLEL to the optic axis will not consist of blended colors. Thus, in many gems, particularly ruby, sapphire, amethyst, kunzite and tourmaline, there is often a subtle change of color from one part of the stone to another as the gem is viewed from different directions; for example, if held toward a strong light, the color seen along the girdle will differ from that seen through the table. This is explained by the fact that light transmitted along the direction of single refraction will be seen as only one color that corresponds to one of the pleochroic colors. In any other direction, pleochroism will be encountered and the apparent color of the stone will be the result of the blended colors.

V. DOUBLE REFRACTION AND PLEOCHROISM IN IDENTIFICATION.

A. Tests for Double Refraction.

Several methods may be employed in order to determine whether a transparent gem possesses double refraction. One of the simplest is to look through the table of a stone using magnification and observe whether the edges between the back facets appear as single or double images. Through practice, one may become sufficiently proficient to distinguish the difference between ruby, which has a low birefringence, and red spinel and red garnet, both of which are singly-refractive. As mentioned before, this is also a way to distinguish colorless zircon or synthetic rutile, which are doubly-refractive, from diamond, which is singly-refractive. Since glass is singly-refractive, the test may also be helpful in distinguishing between doubly-refractive stones and glass.

Because one might look along one of the directions of single refraction in a doubly-refractive stone, the stone should be examined in at least three, preferably more, directions. The doubling of the edges increases from none, parallel to the optic axis (the direction of single refraction), to a maximum at right angles to the optic axis. When first seen by a student, the doubled facet edges are often likened to the appearance of railroad tracks.

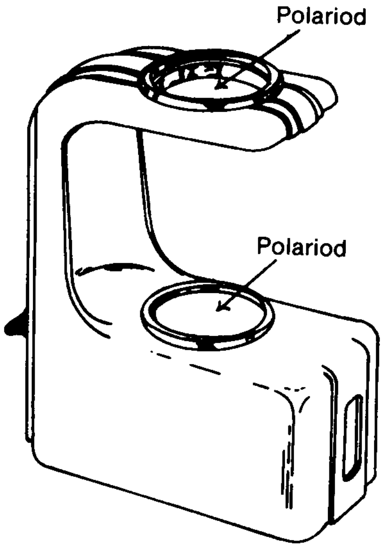


Figure 8

The POLARISCOPE (pronounced po-LARE-uh-scope, Figure 8) is an inexpensive and very satisfactory instrument for the detection of double refraction. It employs two Polaroid (trademark) plates. Polaroid is made by bonding a very strongly dichroic material composed of tiny crystals in optically parallel positions on plastic film. Thus, they behave as a single large crystal plate, the dichroism of which is so strong that light in one of the two vibration directions is almost totally absorbed, whereas the other direction passes light readily. Therefore, only light vibrating in a single direction can pass through the Polaroid.

The Polaroids can be positioned so that little or no light is allowed to pass. The gem is then placed between the polarizers. If the gem is doubly refractive and is not being observed parallel to an optic axis as it is rotated, it will appear dark at every 90 degree position and light at the intermediate position. In other words, it blinks from light to dark. Amorphous materials and gems of the cubic system are not doubly refractive and do not affect light in this manner; they remain dark in all positions and do not blink when viewed between the polarizers. In order to be sure that observations are correct, it is necessary to view the gem through several directions.

Some singly-refractive gems show ANOMALOUS (pronounced ah-NAHM-ah-luss), or false, double refraction, which is caused by internal strain. Practice with the use of the polariscope soon enables one to distinguish between anomalous double refraction and true double refraction. This will be discussed further in the Gem Identification Course and the Handbook of Gem Identification.

B. Tests for Pleochroism.

Pleochroism is most easily observed with a DICHROSCOPE (pronounced DYE-kro-scope), a small instrument that is capable of separating the two polarized beams so that they can be seen separately. Looking through a dichroscope, one sees twin images of the small opening in the opposite end of the instrument. When a dichroic stone is viewed, the two halves of the circle may appear different colors (Figure 9). Since these two halves appear side by side, it is possible to observe even weak dichroism. The colors of trichroic gems may be observed by first viewing one pair of colors and then shifting the gem with respect to the dichroscope and viewing a second pair, one of which is repeated from the first. It is necessary to observe a gem along at least THREE directions before deciding it is NOT pleochroic, in order to be sure that the optic axes have been avoided.

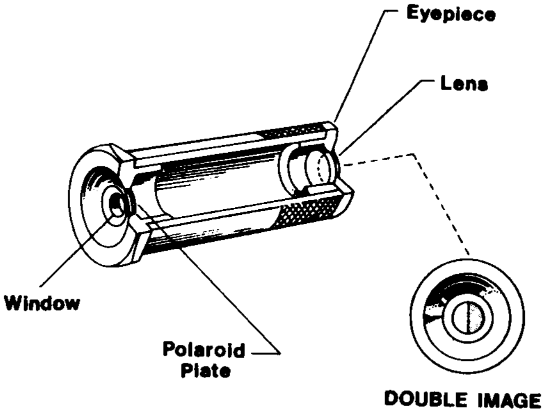


Figure 9

Both the strength of the pleochroism observed and the colors seen are taken into consideration in identifying the gem. Degrees of pleochroism are expressed as very strong, strong, distinct, weak, and very weak.

In his early observations with the dichroscope, the student gemologist usually expects to see a great difference between the pleochroic colors. New students often decide that gems exhibiting weak or even distinct pleochroic colors have no pleochroism whatever, because the difference between the colors is not obvious. The ability to detect weak and very weak pleochroism increases with practice. Often one color will be simply a trifle lighter or darker or of a slightly different hue.

Pleochroism may also be observed with the polariscope, by turning the upper Polaroid so that maximum light is transmitted through the polariscope and rotating the gem between the polarizers. If it is a pleochroic gem and is not being observed parallel to an optic axis, it will change color during the rotation. As a rule, weak pleochroism is more difficult to observe with the polariscope than with the dichroscope, since the colors cannot be seen side by side. But even fairly weak color differences are evident to an observer who has had sufficient practice in using a polariscope.

The primary value of the observation of pleochroism is that its presence is PROOF OF DOUBLE REFRACTION. The polariscope will detect doubly-refractive gems by their blinking reaction even if they are colorless or very pale in color. Colorless stones do not show pleochroism, so this determination is not possible with the dichroscope. However, the dichroscope does show the exact NATURE of the pleochroic colors when present, an observation that is sometimes of value in identification. Moreover, the dichroscope does not show pleochroism in those ordinarily singly-refractive colored materials that exhibit anomalous double refraction in the polariscope. As stated previously, experience usually permits the observer to distinguish between true and anomalous double refraction in the polariscope, but this distinction is sometimes difficult. Generally speaking, the polariscope is a more valuable testing instrument than the dichroscope. For best results in gem testing, however, it is advisable that the two be used in conjunction with one another.

PLEOCHROIC COLORS OF SOME OF THE IMPORTANT TRANSPARENT GEM MATERIALS

The symbols S, D, W and VW signify strong, distinct, weak and very weak pleochroism. Only two colors are given for biaxial gemstones when little color difference is detectable between two of the three directions. Colors may vary from those described, depending on hue and depth of color.

UNIAXIAL (DICHROIC)

Zircon	
Blue (S)	Medium blue and colorless to gray.
Green (W)	Brownish green and green.
Orangy Brown (W-D)	Brownish yellow and purplish brown.
Corundum & Synthetic Corundum	
Ruby (S)	Violetish red and orangy red.
Sapphire	
Blue (S)	Violetish blue and greenish blue.
Green (S)	Green and yellow green.
Yellow (W)	Yellow and light yellow.
Orange (S)	Yellow-brown to orange and colorless.
Tourmaline	
Green (S)	Blue-green to dark brownish green and yellow-green.
Red (S)	Dark red and light red.
Beryl	
Emerald (S)	Green and blue-green.
Aquamarine (W-D)	Light blue and darker blue.
Golden (W)	Light greenish yellow and light blue-green.
Quartz	
Amethyst (W-D)	Violet or purple to gray-violet.
Citrine (VW)	Light yellow and very light yellow.
Rose (S)	Brownish red and light pink.

BIAXIAL (DICHROIC OR TRICHROIC)

Chrysoberyl	
Alexandrite (S)	Dark red-purple, orange, and green.
Yellow (D)	Colorless, very light yellow, and greenish yellow.
Peridot (W)	Yellow-green and green.
Spodumene	
Kunzite (S)	Violet to purple and colorless to pink.
Topaz	
Blue (W-D)	Colorless and light blue.
Yellow (D)	Brownish yellow, yellow, and orange-yellow.
Brown (D)	Yellow-brown and brown.

BIREFRINGENCE OF THE COMMON GEM MATERIALS AND RELATED SUBSTANCES

This table includes only those doubly-refracive materials that may possess sufficient transparency to make the visual detection of birefringence practical.

Syn. Rutile	.287
Zircon (High)	.059
Zircon (Medium)	.006 - .050
Zircon (Low)	.002 - .005
Corundum	.008
Syn. Corundum	.008
Chrysoberyl	.009
Rhodonite	.010
Idocrase	.005
Zoisite	.013
Diopside	.026
Spodumene	.016
Peridot	.036
Andalusite	.008 - .013
Tourmaline	.020
Topaz	.008
Rhodochrosite	.220
Beryl	.005 - .009
Syn. Emerald	
(Hydrothermal)	.005
(Flux)	.003
Labradorite	.009
Quartz	.009
Iolite	.009
Oligoclase	.008
Albite	.011
Orthoclase	.008
Calcite	.172